Chapter 13

Status of Siting and Host Rock Characterization Programme for a Geological Repository in India

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13.1 Introduction

The Indian programme in search of suitable sites for location of a deep geological repository for disposal of high level vitrified waste has been in progress for the last few years. The whole country has been screened, based on well identified criteria, for suitable host rock formations in tectonically stable areas. The programme is being pursued in a phased manner in stages, to narrow down the choice from larger areas to a few candidate sites of specific size. In parallel, a study is underway to directly evaluate and characterize the host rock lying within the exclusion zone of a nuclear power plant for locating a possible waste repository.

The main host rock under consideration is a plutonic granitic formation available in tectonically stable areas and having homogeneous and uniform geological, structural, physico-chemical and hydrogeological characteristics with a favorable socioeconomic environment.

Out of thousands of square kilometers of granitic areas screened, the choice has been narrowed down to a few granitic zones of 100 - 150 sq. km. Two such zones have been investigated in detail to further demarcate the most suitable sub-zones. Micro level investigations are to be taken up in the sub-zones to assess the possibility of finding the repository candidate sites.

In one of the sites, geological, hydrogeological, geophysical (preliminary), environmental and socioeconomic surveys have been completed, whereas in the other, deep drilling down to a depth of 620 metres is in progress. Simultaneously, laboratory investigations to evaluate mineralogical, petrographical, micro-structural, thermal, mechanical, physical and chemical properties of the rockmass are also in progress. Modeling studies for joint fracture characterizations, ground water flow and radionuclide migration, and stress behavior in a conceptual repository have been taken up. Geophysical surveys, bore hole logging and *in-situ* stress measurement are underway.

13.2 Repository Site Selection Programme

The programme is aimed at selecting one or more geological repository sites and characterizing them for final disposal of immobilized high level radioactive waste, through various stages of investigations comprising field and laboratory studies. To carry out the multi-disciplinary investigations, a number of national expert organizations/agencies have been involved to address specific issues.

13.2.1 Major Site Selection Criteria

The major criteria on which the selection of a candidate repository site depends are:

- Tectonic stability of the area;
- Three dimensional homogeneity, large extent and massiveness of the host rock mass;
- Suitable hydrological and hydrogeological environment;
- Favorable thermal, thermomechanical and geochemical properties of host rock; and
- Favorable socioeconomic factors.

13.2.2 Stages of Site Selection

The approach followed for site selection is to narrow down the choice of the area with an increasing level of confidence. This is planned to be achieved in different stages, reducing the size of the area to smaller entities at every stage. The following main stages are considered:

Stage I. Collection of all available data from various sources and their interpolation to evaluate specific attributes for delineating promising zones. Such data have already been generated and a few zones have been identified for further investigations.

Stage II. Mainly semi-detailed studies including data generation through field surveys, geological mapping, hydrological investigations, collection of soil/rock/water samples and their analysis. Based on the data generated during these investigations, two zones have been identified for further studies.

Stage III. Extensive field surveys, detailed geological and structural mapping, subsurface investigations and intensive analysis and interpretation of all parameters. Detailed geological and structural mapping of the potential zones has already been initiated. Subsurface investigations have also been planned in this stage.

Stage IV. Micro level studies, subsurface characterization with the help of geophysical investigations and ground water flow studies.

Stage V. Finalization of site for pilot repository from one of the selected sites. Further detailed investigations by conducting *in-situ* experiments.

Stage VI. Final stage involving actual design and construction of a full fledged repository.

13.2.3 Evaluation of Zones and Methodology

Based on the criteria developed, a number of attributes have been identified for data acquisition, collation and interpretation. An attribute is a factor or a parameter having varying degrees of influence on the geological, mechanical, hydrological, thermal and radiological integrity of the proposed repository. Each attribute has been allotted a weighting factor depending upon its relative importance at each stage of repository siting. In Stage I, 20 attributes as listed in Table 13.1 were thoroughly examined. Each attribute was allotted a maximum score point of 10 and a minimum of 0. These attributes have been organized and grouped based upon their relative merits in different stages of the programme.

Initially geological, structural, tectonic, geomorphological and socioeconomic data were collected and represented on 1:25,000 scale for further evaluation. All the granitic areas were then divided into grids of 20 x 20 km or 10 x 10 km. Each unit was taken as a candidate unit for matrix analysis. The units scoring maximum points were considered as promising zones for further evaluation. Based on the product of score points for each attribute and the corresponding weighting, a relative grading was determined using the following equation:

Table 13.1. List of attributes considered in Stage 1.

No.	Attribute
1.	Lithological formation
2.	Seismicity
3.	Distance form stuctural discontinuities
4.	Distance from surface water bodies, viz. dams/rivers/lakes, etc.
5.	Ground water level
6.	Rainfall
7.	Surface water runoff
8.	Population
9.	Distance from economic mineral occurrences and mining activities
10.	Distance from industrial/archeological/tourist/religious spots
11.	Floods
12.	Soil cover and weathering pattern
13.	Vegetation cover
14.	Accessibility of the area
15.	Intensity of intrusives, veinlets, etc.
16.	Joint patterns, fracture pattern, etc.
17.	Topography
18.	Dip of formation/foliation
19.	Homogeneity of rock mass
20.	Political awareness

$$GI = \Sigma \; Wi \times Pi$$

where: Wi = weighting factor of attribute, Pi = Score points against an attribute, and GI = grade index for suitability.

Until now, this methodology has been adopted in Stage I and has enabled an identification of two favorable zones of 100 to 150 sq. km for detailed investigations in Stage II.

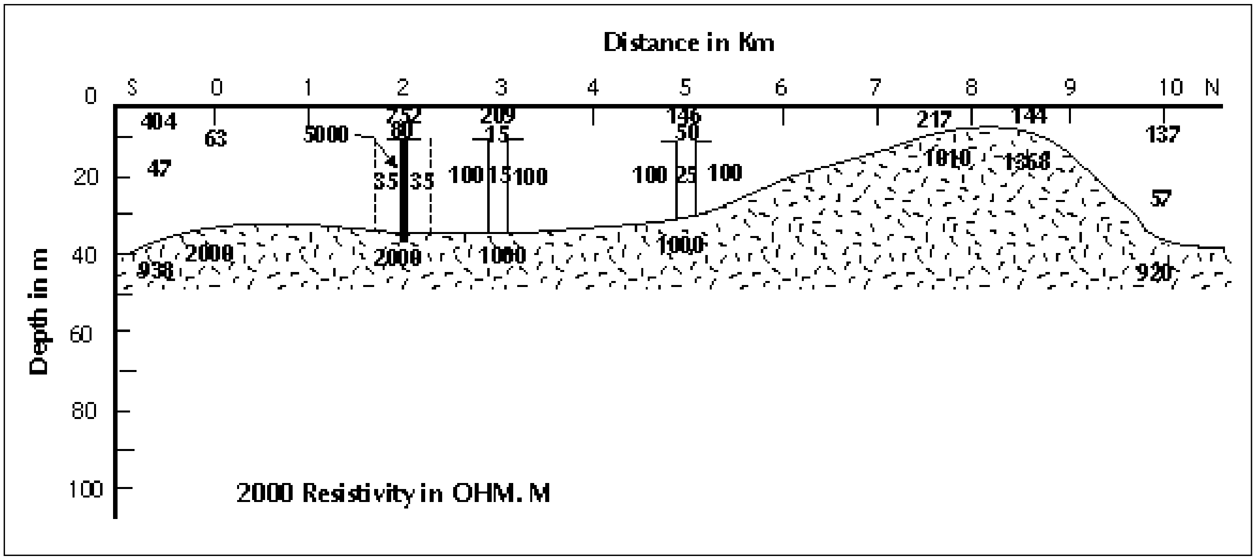

Figure 13.1. A resistivity section along the main N-S traverse P1, based on joint DCR and HLEM 1-D inversion and limited 3-D modeling.

In the second stage, demarcation of two zones of 25 to 30 km^2 has been achieved. In the third phase, further narrowing down of these zones to those of four sq. km each will be considered. They will then be treated as test or candidate sites.

The methodology adopted in this programme has been found to be most suitable. Subsurface investigations have now been planned for further characterization of the granitic rockmass. The zones so far identified largely satisfy the conditions of compositional and structural homogeneity, massiveness and a suitable hydrogeological set-up. The rainfall in these zones is scanty, population density very low, and vegetation cover almost negligible.

13.3 REPOSITORY SITE CHARACTERIZATION PROGRAMME

While characterizing a particular rock formation for its structural and compositional homogeneity, a thorough assessment of its geological, structural, hydrogeological, geophysical and petrographic characteristics is essential. In addition to the above investigations, it is also required to study various thermal and mechanical properties of the rockmass so as to understand its behavior at elevated pressures and temperatures.

13.3.1 Geophysical Characterization

Geophysical surveys involving electrical methods were carried out at one of the promising zones to test the suitability of various methods to evaluate the homogeneity of the granitic rock mass under investigation and detection of fracture zones, intrusive rocks etc. The observations were recorded over a path length of 12 km at an interval of 100 m. The line was so selected as to almost bisect the area. The following methods were employed to achieve the objective:

1. Direct Current Resistivity (DCR) method to obtain information at greater depths;
2. Horizontal Loop Electro-Magnetic (HILEM) method to probe shallow depths; and
3. Very Low Frequency (VLF) method to get near surface information.

Based on the data obtained, it has been interpreted that beneath a sandy top cover, weathered to semi-weathered granite exists between varying depths of 7 to 60 m below the surface with unweathered fresh granite below these depths. Adyke was also demarcated along the line of a survey. Figure 13.1 shows the vertical section along this line.

Besides these surveys, a seismic sounding was also carried out over selected outcrops along two short orthogonal lines using a hammer source. This experiment was conducted for studying seismic propagation characteristics of the area when there is little or no sand cover.

From the above investigations, the following possible

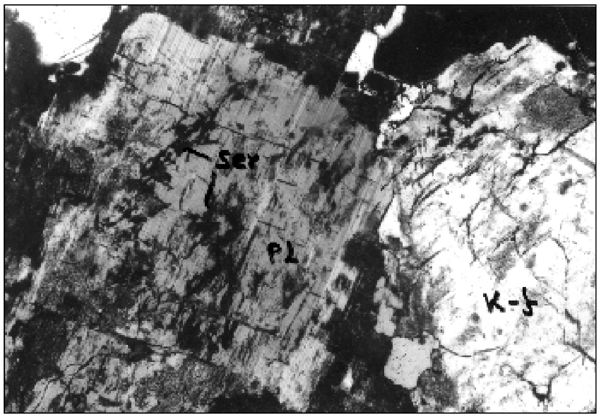

Figure 13.2. Plagioclase feldspar (P1) and K-feldspar (k-f), filled with sericite in a thin section of granite. Network of microcracks are also observed. Under crossed polars (x16).

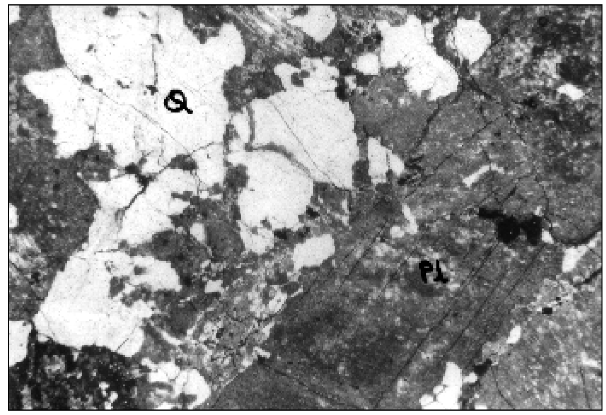

Figure 13.3. Microcracks in quartz and plagioclase (P1) in a granite thin section. Under crossed polars (x16).

subsurface conditions have been brought to light:

- Extensive cover of loose sand;
- Low resistivity near the surface indicating higher degree of weathering of the top zone;
- Highly variable surface and near surface electrical resistivity and seismic velocity; and
- Possible presence of shallow anomalous objects within deep weak zones in granite.

It may, however, be noted that these interpretations are based on a single test survey. More detailed investigations are planned in the near future, using advanced techniques like a Multi-channel Digital Data Acquisition System, which will retrieve very weak signals from greater depths.

A resistivity survey on a grid interval of 5 x 5 km or 10 x 10 km will be conducted shortly to assess the major elements of inhomogeneity in the rock mass down to a depth of 1 km.

13.3.2 Petrographic Characterization

Petrographic examination of selected samples of granite in the area under investigation was carried out to understand the microscopic features of the rocks. The following parameters were emphasized:

- Deformation and consequent stress effects on mineral grains, especially quartz;
- Presence of microfractures in the rock;
- Nature of alteration of constituent minerals; and
- Radioactivity of constituent minerals.

The salient petrographic features of granite in one of the zones are as follows:

- The rocks can be classified as porphyritic micro granites, micro diorites and porphyritic granophyres, with major quartz (30% to 45%), potash feldspar (22% to 54%) and plagioclase feldspar (12% to 28%). Accessory minerals include biotite, chlorite, epidote, apatite and opaques, mainly oxides of iron and titanium;
- Feldspars have undergone a considerable degree of weathering and have been sericitised. Biotites have been chloritised;
- In general, the overall degree of alteration of granites is moderate, as supported by weathering index data;
- Radioactive assay data for these samples indicate that the granite contains 15 to 20 ppm eU_3O_8. Solid State Nuclear Track Detection (SSNTD) studies indicate that no discrete radioactive phase is present in the samples; and
- In most samples, quartz is unstained and microcracks are not widespread.

The above observations suggest that the granite rock mass under investigation could form a suitable host rock from the petrographic point of view. Figures 13.2 and 13.3 show mineral assemblages and micro fractures in

Table 13.2. Compressive strength of heat treated granite.

No. of Samples	Thermal Treatment Temperature (°C)	Unaxial Compressive Strength (MPa)	Average Strength (MPa)	Standard Deviation
14	unheated	205, 194, 193 210, 205, 206 216, 196, 207 184, 192, 220 204, 209	202.93	9.96
08	100	226, 241, 208 215, 215, 225 209, 201	217.50	12.69
09	200	230, 231, 223 218, 206, 233 246, 224, 216	225.22	13.52
12	400	195, 201, 204 207, 215, 224 221, 198, 196 197, 195, 201	204.50	10.20
02	600	125, 142	133.50	

typical pink granite of the area.

13.3.3 Thermomechanical Characterization of Rock

The objective of carrying out mechanical studies on the rock samples is to understand the behavior of the rock mass at normal and elevated pressures and temperatures. This would help in modeling fracture/joint systems and to evaluate the stability of the repository.

The study pertains to the development of fractures and extension and enlargement of existing fractures, when subjected to heat induced stresses. These investigations were carried out with an Acoustic Emission Monitoring System and a High Temperature-High Pressure Triaxial Cell.

Salient features of the laboratory studies carried out are as follows:

- Uniaxial compressive strength of granite, heated to 200˚- 245˚ C is higher than unheated and heated to 100˚, 400˚ and 600˚ C samples (Table 13.2);
- Heat treated granite and charnockite undergo more axial strain and less lateral strain compared to unheated samples;
- Young's Modulus decreases with increasing temperature (Table 13.3);
- Higher stress is required to generate acoustic emission events in case of granite heated to 200˚ C;
- Triaxial compression experiment carried out at a confining pressure of 30 MPa indicates that the average strength of granite at 200˚ C is higher than that at 100˚ C and 150˚ C, but lower than the unheated samples (Fig. 13.4). Sample heated to 200˚ C undergoes more axial deformation;
- Uniaxial compressive strength decreases with increase of water content in the samples; and
- Preliminary analysis of results of uniaxial compressive tests and acoustic emission experiments on heat treated rocks (heated up to 245˚ C) appears to indicate that microcracks strengthen the rock material like dislocations in metals.

In-situ thermomechanical experiments were carried out

Table 13.3. Effect of temperature on Young's modulus.

Heat Treatment Temperature (°C)	Average Young's Modulus (GPa)
Unheated	74
100	72
200	71
300	67
400	62

in two underground chambers at a depth of 1000 m in a mine facility to study the behavior of host rock subjected to decay heat generated by high level vitrified radioactive wastes. The waste containers were simulated by electrical heaters of the same dimensions. Thermocouples, vibrating wire stress meters and extensometers were installed in the bore holes within and around the array of heaters to measure temperatures, stresses and expansions in the rockmass. The main results of single and multi-heater experiments have shown that:

- The observed temperature profiles match with those of predicted ones in the majority of monitoring points. Atypical profile is shown in Figure 13.5;
- The observed heat induced stresses are about half the values of the predicted stresses, the maximum value being 45 MPa; and
- The extension of the rockmass was found to be negligible.

13.4 CAPTIVE SITE EVALUATION PROGRAMME

Under this programme, a charnockite rock formation has been identified for designing an underground facility. The proposed site is presently being evaluated to assess its suitability with respect to geology, structural features, ground water conditions, and the thermal and mechanical integrity of the rockmass.

In this connection, the proposed site has been studied by geological and structural mapping, resistivity surveys, soil profiling and physico-chemical analysis. Currently, deep drilling operations at the site are in progress. Three bore holes of more than 600 m depth have already been drilled and a few more are planned. Core samples from them are being studied for mineralogy, structural homogeneity, geochemistry, and thermomechanical properties. Further evaluation will be carried out by geophysical logging techniques in the bore holes to have a better understanding of the subsurface features. The measurements of *in-situ* stresses and permeability in the bore holes are to be undertaken shortly. Cross-hole seismic tomography is also planned. The study of cores indicates that the rock is massive without many open joints and fractures. Long, intact core lengths up to 6.0 m (Fig. 13.6) have been recovered from the bore holes. The ground water aquifer is confined to shallow depths in soil and weathered zones. The water is saline to some

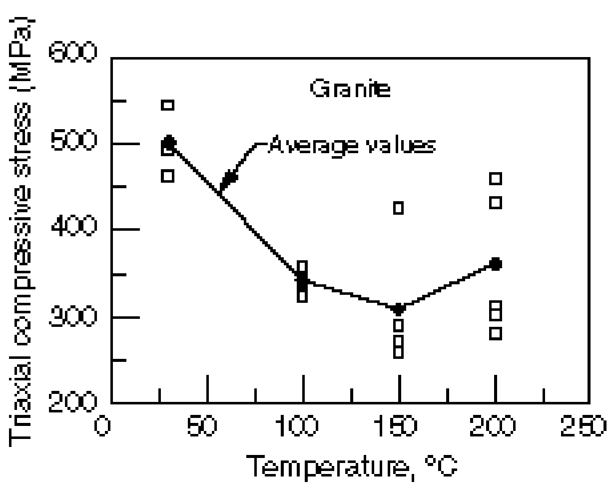

Figure 13.4. Triaxial compression test showing temperature-strength relationship.

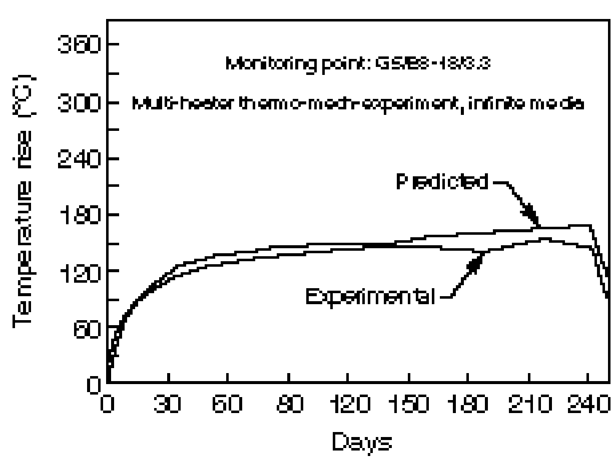

Figure 13.5. Typical profiles from *in-situ* thermomechanical experiment.

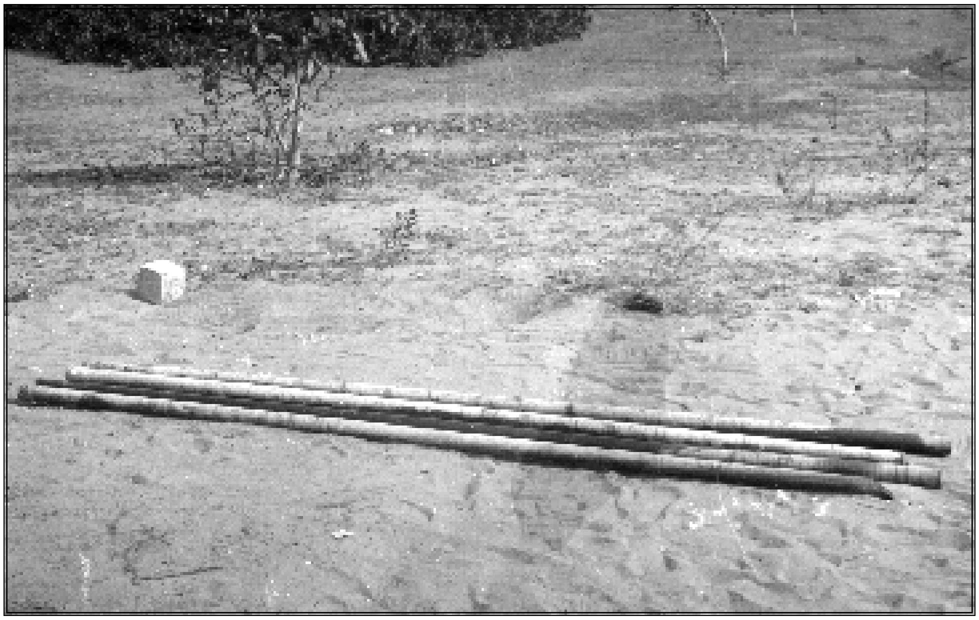

Figure 13.6. Intact long borehole core samples from charnockite formation.

extent, and the rock has good sorption properties.

13.5 CONCLUSION

The Indian programme of siting and host rock characterization for a geological repository in granite comprises selection of a site by the method of narrowing down the choice from larger areas to a specific site, on the one hand, and directly characterizing a known potential host rock formation within the captive area of a nuclear site, on the other.